Journal of Applied Veterinary Sciences, 10 (1): (2025) proof
ISSN: Online: 2090-3308, Print: 1687-4072
Journal homepage : https://javs.journals.ekb.eg

The Different Influences of a Phytobiotic, Green Tea (*Camellia sinensis* L.) on the Poultry Health and Production

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ABSTRACT

The incorporation of antimicrobials in poultry production systems has been linked with the development of resistant bacteria that spread to the environment, transmit to humans, and consequently induce a serious risk for public health. Therefore, searching for natural antibiotic alternatives could help in minimizing the harm to food safety, environmental contamination, and the overall health hazard. Phytobiotics are effectively used as antimicrobial feed additive alternatives worldwide. Many phytochemicals found in herbs, spices, plant extracts, and essential oils have demonstrated potential bioactivities, including antioxidant, antimicrobial, immunomodulatory, and anti-inflammatory properties. Tea is included in the list of phytogenic substances with numerous health benefits. Green tea (GT) (*Camellia sinensis*) has more than 200 bioactive compounds and 300 different substances, including polyphenols, alkaloids, volatile oils, amino acids, polysaccharides, lipids, vitamins, and minerals. In poultry production, the dietary GT and its derivatives (extract, leaves, by-products, polyphenols, and flowers) are supplemented for improving performance, immunity, and blood parameters; alleviating stressors and reducing microbial infections. Therefore, this article was designed to investigate the different influences of using GT as a feed additive in the poultry production system regarding its effects on the production performance of broilers and layers, carcass characteristics, oxidative stressors, blood parameters, immunity, and microbial balance.

Keywords: Antioxidant and antimicrobial, Blood parameters, Green tea, Immunity, Poultry performance.

Original Article:

Received
Accepted
Published in

***J. Appl. Vet. Sci., 10(1)*: Proof**

INTRODUCTION

Despite the continuous improvement of feed utilization efficacy, the problems of tissue drug residues and the development of resistant bacteria may lead to reduced antimicrobial efficiency with human health hazards **(Abreu *et al*., 2023; Kamouh *et al*., 2024)**. Therefore, the European Union prohibited the use of antimicrobial feed additive growth promoters in 2006 in several countries **(Castanon, 2007; WHO, 2017)**. Moreover, the United States Food and Drug Administration presented guidance to phase out growth-promoting antimicrobials and keep the use of them in food animals under veterinary supervision. Therefore, searching for and developing new antibiotic alternatives and substitute products has become an urgent issue **(Azizi *et al*., 2024)**. Nowadays, with careful evidence of synthesis and translation, phytochemical feed additives provide poultry production with approved and commercially viable antibiotic alternatives **(Abd El-Ghany, 2020a, b; Abd El-Ghany and Eraky, 2020; Abd El-Ghany, 2022; El-Sayed *et al*., 2022)**. Phytochemicals have been widely used as poultry feed additives to effectively replace antimicrobials, improve overall poultry production, enhance immunity, possess antioxidant, antimicrobial, and anti-stress characters, and modulate the gut microbiota **(Abd El-Ghany and Babazadeh, 2022**; **Al-Mnaser *et al*., 2022; Hassan *et al*., 2022; Azizi *et al*., 2023)**.

Special attention has been paid toward many herbs such as tea, as a type of alternative phytochemical. Tea (*Camellia sinensis* L.) is a perennial, evergreen, and cross-pollinated plant with white flowers and green fruits as well as two or three seeds **(Khan, 2014)**. Tea was accidentally discovered in China in 2737 BC **(Wheeler and Wheeler, 2004)** and had been used for beverages in most worldwide countries for thousands of years for the potential health promotion **(Wei and Meng, 2011)**. There are differences in the colours, flavours, and names of tea depending on the leaves processing. Moreover, tea can be categorized into three types according to the degree of fermentation: unfermented tea, partially oxidized tea, and fully fermented tea **(Chan *et al*., 2011)**. Besides, four different types of tea can be produced according to oxidation degree: white (oxidized and the least processed of all teas), green (oxidized, less processed, and not fermented), oolong (partially oxidized and falls between black and green), and black (completely oxidized or fermented, and leaves change from green to black) **(Khan, 2014)**.

Green tea (GT) is an herb that can enhance poultry health and improve the nutritional quality of products **(Chen *et al*., 2019)**. GT has over 200 bioactive compounds and contains over 300 different substances including polyphenols (L-theanine) which accounts for more than half of the total amino acids **(Khan, 2014),** as well as catechin, epicatechin, gallocatechin, epigallocatechin, gallocatechingallate, and epicatechin gallate are the main flavan-3-ols antioxidants **(Ninomiya *et al*., 1997; Angga *et al*., 2018)**. Flavonoids, polyphenols, theophylline, caffeine, theobromine (methylxanthine), L-theanine, flavonol glycosides (quercetin, kaempferol, and myricetin), flavonol glycosides, amino acids, polysaccharides, aglycones, volatile oils, vitamin C, and minerals have also been biologically active components present in GT **(Saptadip, 2002; Cabrera *et al*., 2003)**. However, the concentration of these bioactive components in GT varies according to the origins and varieties **(Younes *et al*., 2018)**. The air-dried GT leaves contained 92.20% dry matter, 82.40% organic matter, 36.21% nitrogen-free extract, 19.32% crude fiber, 18.15% crude protein, 9.80% ash, 8.72% ether extract, 7.80% moisture, and 3002 kcal/kg of metabolizable energy **(Abdo *et al*., 2010)**.

From the abovementioned, the aim of this review article was the investigation of the different influences of using GT as a feed additive in the poultry production system regarding its effects on the production performance of broilers and layers, carcass characteristics, oxidative stressors, blood parameters, immunity, and microbial balance.

Production performance of broilers and layers

The different influences of using GT in the poultry production systems **(Fig.1).**

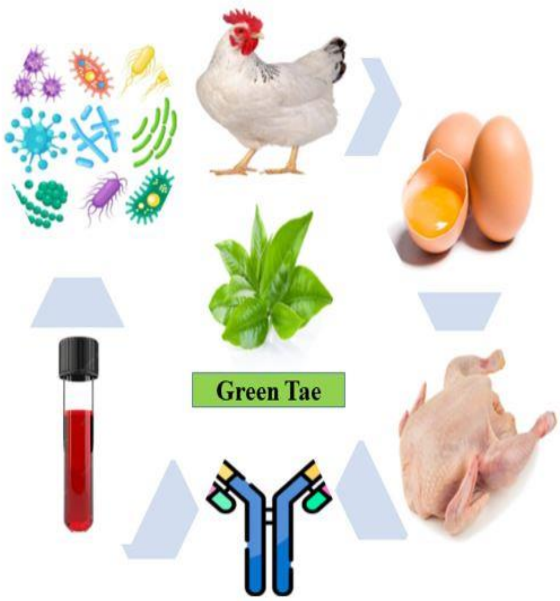

Fig. 1: The different influences of using green tea in the poultry production systems

The influence of using GT on the production performance of broiler and layer chickens is summarized in **Table (1).**

Table (1): The different effects of the dietary green tea on the performance of broilers and layers.

Dietary level	Type of chickens	Effects	Reference
0.67% Japanese GT extracts	Layer	↓ Egg weight ↑ Haugh unit ↑ Albumen height and physical stability ↓ Fat content of egg yolk	**Yamane *et al*. (1999)**
0.60% Japanese GT	Layer	No effect on egg production rate ↑ Haugh unit ↑Albumen height and physical stability	**Biswas *et al*. (2000)**

0.50%, 0.75%, 1.00%, and 1.50% GT powder	Broiler	↓ FI ↓ BWG (high dose) and improved FCR	**Biswas and Wakita (2001a)**
0.30% GT powder	Layer	↓ Average egg weight ↑ Haugh unit, and albumen percentage ↓ Yolk percentage and cholesterol content	**Biswas and Wakita (2001b)**
1.00%, 2.50% and 5.00% GT	Broiler	↓ BWG	**Kaneko *et al*. (2001)**
0.5%, 1%, and 2% GT by-products	Broiler	↑ BWG	**Yang *et al*. (2003)**
0.20% GT	Layer	↑ Egg production and egg mass	**Al-Harthi (2004)**
1.00% to 1.50% GT	Broiler	↓ BWG	**Uuganbayar (2004)**
0.5%, 1.0%, 1.5% and 2.0% GT powder	Layer	No effect on egg production rate and eggs' weight ↓ Eggshell thickness and cholesterol and thiobarbituric acid in egg yolk ↑ Yolk colour score (yellowness of egg yolk) (2.0% level) No effect on cholesterol in egg yolks	**Uuganbayar *et al*. (2005)**
1.00% or 2.00% Korean, Japanese, and Chinese GT	Layer	↑ Egg production rate ↓ Eggshell thickness and shape index No effect on juiciness, texture, flavor, and acceptability of boiled eggs No effect on albumen index, yolk index, and Haugh unit ↓ FI ↓ Total cholesterol in egg yolks	**Uuganbayar *et al*. (2006)**
5% to 10% GT powder	Layer	↓ Laying rate	**Kojima and Yoshida (2008)**
1.00%, 5.00%, and 10.00% GT	Layer	No significant effect on egg weight, egg production rate, egg mass, yolk colour fan score ↓ Eggshell strength, thickness, and Haugh unit	**Sadao and Yuko (2008)**
1.00% to 5.00% GT leaves 0.5L/ 100 kg to 2.5 L/100 kg GT aqueous extract	Layer	↑ Egg production, egg mass, and FCR ↑ Thickness of egg shell and yolk colour score	**Abdo *et al*. (2010)**
0.5% and 1.0% GT	Broiler	↑ BWG	**Sarker *et al*. (2010)**
0.50% GT extract and 1.50% GT powder	Layer	No effects on FI, egg production, and egg weight ↓ Egg yolk cholesterol and triglyceride contents	**Ariana *et al*. (2011)**
0.1 or 0.2 g/kg GT extract for 6 weeks	Broiler	↑ Feed efficiency	**Erener *et al*. (2011)**
0.1 g/kg or 0.2 g/kg liquid hydroalcoholic extract of GT	Broiler	↑ BWG, FI, and feed efficiency	**Guray *et al*. (2011)**

300 mg/kg of GT extract	Broiler	No significant difference in growth performance	**Khalaji *et al*. (2011)**
1.0%, 2.0%, or 4.0% GT powder	Broiler	No significant difference in BWG, FI, and FCR	**Shomali *et al*. (2012)**
200 mg/kg of GT extract	Broiler	↑ Growth performance	**Shahid *et al*. (2013)**
1 g/kg GT	Layer	No significant effects on the laying performance, eggshell thickness, and Haugh unit	**Al-Harthi (2014)**
0.00%, 1.50%, and 2.00%) fish oil, 0.00%, 1.00%, and 1.50% GT powder, and their combination	Broiler	↑ FI & Final BWG ↓ FCR	**Saraee *et al*. (2015)**
0.5, 1, and 1.5% GT powder	Broiler	↓ FI	**Hrnčár and Bujko (2017)**
0.1% GT powder	Layer	↑ Laying rate, egg quality, egg mass, and physiological performance	**Rizk *et al*. (2017)**
0.5% and 1.0% GT powder	Broiler	↓ FI No effect on growth rate	**Rahman *et al*. (2018)**
1% and 3% GT powder	Layer	↑ Albumen height and Haugh unit	**Xia *et al*. (2018)**
2% GT powders	Broiler	↑ Daily BWG ↓ FCR	**Aziz-Aliabadi *et al*. (2023)**
0.500 g and 0.750 g/kg GT powder for 6 weeks	Broiler	↑ Live BWG and FI ↓ FCR	**Abo El-Maaty *et al*. (2023)**
0.5% and 0.75% GT	Layer	↑ Hen-day egg production rate ↑ Albumen height ↑ Haugh unit ↓ FCR	**Li *et al*. (2023)**

GT= Green tea ↑= Increase ↓= Decrease BWG= Body weight gain FI= Feed intake FCR= Feed conversion ratio

The health and the production performance parameters of broiler chickens were enhanced when they were fed on diets containing GT. The GT leaves, their by-products, and tea polyphenols could reduce mortalities in diseased broilers **(Cao *et al*., 2005)**. Several previous studies showed an improvement of the body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR) of broilers following supplementation with GT and its derivatives **(Yang *et al*., 2003; Erener *et al*., 2011; Shomali *et al*., 2012; Abo El-Maaty *et al*., 2023; Aziz-Aliabadi *et al*., 2023**). Even under heat stress conditions, the feed supplemented with GT extract resulted in an increase in the feed efficiency, live body weight, and production rate **(Abd El-Hack *et al*., 2020)**.

This enhancement in performance parameters of broilers could be attributed to the catechins, flavonoids, and flavonols, bioactive substances in the unfermented GT powder **(Erener *et al*., 2011; Khan, 2014**). Moreover, boosting immunity and enhancing digestion could help improvement in performance **(Aziz-Aliabadi *et al*., 2023)**. **Guray *et al*. (2011)** concluded that the improved broilers' production after supplementation with added GT extract may be directly associated with some physiological mechanisms such as regulation of the caecal microflora and the intestinal health. For instance, the duodenum and jejunum villus height (VH) were significantly improved in broilers fed on diets treated with GT **(Hassanpour *et al*., 2010)**. Similarly, **Jelveh *et al*., (2022)** reported that the intestinal VH and villus weight were increased after supplementation of chickens with 0.2, 0.3, and 0.4 g/kg GT extract and 1, 2 and 3 g/kg GT powder. Increasing the intestinal VH and VH:crypt depth ratio and reducing apoptosis associated with feeding on GT could positively reflect on the intestinal digestive and absorptive functions and surface area, expression of brush border enzymes, transport systems of nutrients, and body weight **(Mohamed *et al*., 2014)**. Moreover, GT powder affects the energy metabolism via stimulation of lipolytic pathways and downregulation of lipogenic pathways **(Venables *et al*., 2008)**.

However, other studies showed no or negative effects of GT derivatives on the performance parameters (**Biswas and Wakita, 2001a; Cao *et al*., 2005; Hrnčár and Bujko, 2017; Rahman *et al*., 2018)**. The dietary incorporation of GT powder could reduce the FI of broiler chickens **(Jelveh *et al*., 2018; Thomas *et al*., 2022)** or could not significantly improve the FCR **(Rizk *et al*., 2017; Xia *et al*., 2018)**. The reduction of FI after consumption of GT may be due to the bitter taste of tea polyphenols, which might decrease the feed palatability and in turn reduce the average daily FI **(Jelveh *et al*., 2018; Rahman *et al*., 2018)**. Besides, the presence of phenolic acids such as tannins in the leaves of GT could restrict the protein utilization and possibly reduce the host's performance **(Mahlake *et al*., 2021)**.

The discrepancy of the different effects of green tea powder on the performance parameters may be related to the source and composition of the plant (total hydrolysable and condensed polyphenols) and the bird's species and age. Moreover, the differences in the total GT catechin content and its constituents, such as epicatechin, epicatechin gallette, epigallocatechin, and epigallocatechin gallette, may explain the inconsistency of the previous studies' results.

In layers, the supplementation with GT or its derivatives could enhance the egg production parameters **(Abdo *et al*., 2010; Rizk *et al*., 2017; Xia *et al*., 2018; Li *et al*., 2023**) or did not affect them **(Sadao and Yuko, 2008; Al-Harthi, 2014)**. The GT leaves, their by-products, and polyphenols were supplemented for hens to improve the laying performance **(Uuganbayar *et al*., 2006)** and to reduce the eggs' cholesterol content. In quails, **Abdel-Azeem (2005)** found that the addition of GT flower powders at levels of 0.25%, 0.50%, and 0.75% to a diet of layers enhanced FCR, particularly at the 0.75% level. The author attributed this positive effect on FCR to the antimicrobial, antifungal, anti-inflammatory, and antioxidant activities of GT flavonoid contents. Similarly, **Sahin *et al*. (2010)** reported that 200 mg or 400 mg of epigallocatechin-3-gallate of GT improved the FI and egg production in heat-stressed quails.

The thick albumin in layers fed on GT powder could be attributed to the possible transfer of polyphenols in GT into β-ovomucin, which increases albumen durability by forming complexes with proteins and polysaccharides **(Bravo, 1998; Wang *et al*., 2018)**.

Carcass characteristics

The administration of 0.2 g/ kg fresh GT liquid hydroalcoholic extract resulted in a significant increase in the carcass weight, dressing percentage, redness, and yellowness color pigment of the breast meat **(Erener *et al*., 2011)**. Similarly, GT powder showed an improvement of the dressing percentage, decreasing the abdominal fat, and increasing the giblets percentage **(Hrnčár and Bujko, 2017)**. The reduction in adipose tissue layer of the chicken's carcass was also observed due to oral daily administration of GT powder either at 50 or 100 mg/kg body weight for 20 days **(Huang *et al*., 2013)**. Likewise, the quantity and proportion of abdominal fat were significantly reduced with GT powder supplementation **(Biswas and Wakita, 2001a)**. It has been suggested that the decrease in the abdominal fat of broiler carcasses was usually associated with the increase in the dietary GT by-product level **(Yang *et al*., 2003; Guray *et al*., 2011)**. Moreover, a significant decrease in the intestine's weight was reported in broilers fed on diets supplemented with 1% or 1.5% GT powder **(Hrnčár and Bujko, 2017)**. The positive influences of GT on the carcass traits could be attributed to the antioxidant characteristics of polyphenols bioactive compounds **(Anandh Babu and Liu, 2008; Son *et al*., 2023)**. Generally, the antioxidants act by inhibiting the reactive oxygen species produced from free radicals, which cause oxidative stress **(Surai, 2019)**.

On the other side, the dietary incorporation of GT may not influence the carcass parameters **(Hrnčár and Bujko, 2017; Aziz-Aliabadi *et al*., 2023)**. In the study of **Biswas and Wakita (2001a)**, the carcass dressing percentage was not affected by the dietary levels of 0.5%, 0.75%, 1%, and 1.5% of Japanese green tea powder. However, the percentage of thigh meat was increased at 1.5% level feed, whilst that of wing meat was decreased in the treated chickens **(Biswas and Wakita, 2001a)**.

Oxidative stressors

It is known that GT could decrease the stress and enhance the physiological status of the body, which may be due to the antioxidant capacity of its bioactive components. The anti-oxidative activity of GT is greater than that of vitamin E and vitamin C **(Wiseman *et al*., 1997)**. The alleviation of heat stress surrounding birds could be achieved via supplementation with GT extract to keep the equilibrium of oxidation-reduction and moderate the antioxidant properties **(Hu *et al*., 2019; Son *et al*., 2023)**. Besides, the natural antioxidant characteristic of green tree extract may mitigate the heat stress and its adverse effect on chickens' carcass quality **(Hu *et al*., 2019)**.

GT acts as a scavenger for reactive oxygen and nitrogen species. Increasing the activity of serum superoxide dismutase and expression of the aorta's catalase has been reported following the feeding on diets containing GT extracts **(Negishi *et al*., 2004)**; these enzymes are associated with the defense of cells against reactive oxygen species. Moreover, feeding on GT was associated with the reduction of the plasma nitric oxide level, which consequently has a direct impact on the reactive oxygen species **(Yokozawa *et***

***al*., 1999)**. The attenuated binding affinity of hydrogen ions in GT enables their dissociation, allowing them to be powerful scavengers of unstable reactive oxygen species molecules and potentially neutralizing the adverse harmful effects **(Zuo *et al*., 2014)**. Moreover, GT extract could activate the antioxidant system by reducing stress hormones and increasing activities of antioxidant enzymes **(Sahin *et al*., 2010; Hu *et al*., 2019; Hoan *et al*., 2021)**.

GT's catechins can directly improve the total plasma antioxidant or indirectly increase the activity or expression. Catechins are non-toxic, account for 30% of GT dry weight, and contain a large content of polyphenols, which have antioxidant properties with cardiovascular protection, as well as antiviral, anticancer, and antimutagenic activities **(Tang *et al*., 2002; Wolfram, 2007; Du *et al*., 2012; Farahat *et al*., 2016; Zhang *et al*., 2019)**. In addition, catechins may increase vitamin E amounts in the low-density lipoprotein, which could protect the vitamin from oxidation **(Yokozawa *et al*., 2002)**. Tea is rich in polyphenols such as theaflavins, flavonols, phenolic acids, thearubigins, catechins, and L-theanine, which have significant health benefits. Moreover, fresh tea leaves contain other additional compounds, including 3,7-dimethylxanthine, 1,3,7-trimethylxanthine, methylxanthines, organic acids, lignin, pigments, chlorophyll, amino acids, and aromatic compounds **(Graham, 1992),** with many physiological and biochemical functions, including antioxidant and anti-inflammatory effects **(Karori *et al*., 2007; Chen *et al*., 2008; Priyanka *et al*., 2012; Saeed *et al*., 2020)**.

Tea polyphenols can regulate the pathways for cellular signaling, which helps in the prevention of chronic diseases and the regulation of physiological functions **(Truong and Jeong, 2021)**. The polyvalent phenols of the unfermented tea are represented in the aromatic rings and hydroxyl groups' structure, facilitating them to efficiently bind and neutralize the unstable molecules of lipids **(Chaturvedula and Prakash, 2011)**. During the fermentation process of tea, this reaction is attenuated owing to vapor, resulting in a higher concentration of polyvalent phenolic compounds retained in unfermented tea when compared with the fully fermented tea **(Anandh Babu and Liu, 2008)**. Improving the intestinal tissue health, increasing the intestinal VH and VH:crypt depth ratio, and reducing apoptosis may help in enhancing the antioxidant properties of GT **(Aziz-Aliabadi *et al*., 2023)**.

Blood parameters

Table (2) shows the different effects of the dietary GT on the blood parameters of birds. It is important to note that the levels of low-density lipoprotein (LDL), high-density lipoprotein (HDL), triglycerides, and cholesterol are related to lipid metabolism, and they are important for the evaluation of the health status of poultry. The LDL carries cholesterol to tissues, while HDL moves cholesterol in the blood vessels to liver (Alvarenga *et al*., 2011). The dietary supplementation with GT powder may reduce lipids intestinal absorption (Koo and Noh, 2007) and hepatic synthesis of cholesterol (Yousaf *et al*., 2014) and stimulate the fecal-lipid excretion (Matsui *et al*., 2006).

Table 2: The different effects of the dietary green tea on the blood parameters of birds.

Dietary level	Effects	Reference
0.5%, 1%, and 2% GT by-product	↓ LDL cholesterol of broilers ↑ Docosahexaenoic acid inbroilers	**Yang *et al*. (2003)**
5 g/kg GT	No effect on total lipids, cholesterol, aspartate aminotransferase and alanine aminotransferase activities inbroilers	**El-Deek and Al-Harthi (2004)**
0.25%, 0.50% and 0.75% GT powder	↓ Blood lipid fractions in Japanese quail ↑ HDL in Japanese quail	**Abdel-Azeem (2005)**
1.00% to 5.00% GT leaves 0.5L/ 100 kg to 2.5 L/100 kg GT aqueous extract	↓ Total plasma cholesterol and total lipids in layers ↑ HDL in layers	**Abdo *et al*. (2010)**
0.50% GT extract and 1.50% GT powder	↓ Serum cholesterol and triglycerides in layers ↑ Ratios of HDL to cholesterol and HDL to LDL in layers	**Ariana *et al*. (2011)**
500 mg/kg of GT powder	↓ Cholesterol level in broilers	**Khalaji *et al*. (2011)**

1.0%, 2.0%, or 4.0% GT powder	No effect on lipid profile concentrations in broilers	**Shomali *et al*. (2012)**
0.50% GT	↓ Cholesterol level of broilers	**Rahman *et al*. (2018)**
0.75 g/kg GT powder	↓ Plasma uric acid in broilers No effect on bilirubin or HDL	**Abo EL-Maaty *et al*. (2023)**
0.5%, 0.75%, and 1.0% GT	↓ Plasma triglycerides, total cholesterol, plasma LDL, and corticosterone in layers ↑ HDL and bilirubin in layers	**Li *et al*. (2023)**

GT= Green tea ↑= Increase ↓= Decrease
LDL= Low density lipoprotein HDL= High density lipoprotein

The previous studies showed that feeding of birds on diets containing GT could increase the concentrations of plasma HDL but reduce the total cholesterol and triglycerides **(Abdo *et al*., 2010; Ariana *et al*., 2011; Zhou *et al*., 2012; Afsharmanesh and Sadaghi, 2014; Huang *et al*., 2019).**

The early study of **Muramatsu *et al*., (1986)** showed that there was an association between the consumption of GT leaf and the cholesterol level in the liver and muscles. Moreover, the dietary inoculation of GT powder exerted benefits on the levels of LDL, LDL/HDL ratios, and uric acid levels in chickens **(Saraei *et al*., 2016)**. The LDL, cholesterol, and glucose **(Jelveh *et al*., 2022)** as well as aspartate aminotransferase levels **(Son *et al*., 2023)** were reduced due to supplementation with GT. Additionally, the dietary supplementation with GT levels induced a significant increase in the plasma levels of malondialdehyde **(Yokozawa *et al*., 2002)**. Catechins inhibit accumulation of excessive lipid in the liver and prevent lipid absorption in the intestine of poultry **(Abd El-Hack *et al*., 2020)**. Therefore, GT could reduce the plasma concentration of cholesterol **(Yang and Koo, 1997)**. In addition, **Yang *et al*., (2019)** reported that dietary supplementation with tea polyphenols significantly decreased the serum total protein levels, which may indicate that tea polyphenols may help in prevention of liver disorders **(Ikuko *et al*., 2010)**.

It is known that cholesterol is biosynthesized by liver of layers and combined with vitellogenin and LDL particles, which are secreted into the blood and then taken up by oocytes by receptor-mediated endocytosis **(Elkin, 2006)**. So, the decrease in the cholesterol content in egg yolk depends on the reduction in synthesized cholesterol by the liver. Therefore, the reduction in the cholesterol and total lipid may be attributed to the effect of GT by-products on 3-hydroxy-3-methylglutaryl coenzyme A reductase of liver which is essential for the synthesis of hepatic cholesterol **(Ariana *et al*., 2011)**. The transformation of cholesterol to bile acids occurs in the liver, which is the principal pathway for the cholesterol removal from the body. This may also explain the reduced cholesterol levels. The content of liver cholesterol could be explained by the muddled effect of GT catechins on micelle formation. Also, bile acids are reabsorbed micelles formed from the small intestine. Catechins inhibit the bile acids reabsorption by distressing the formation of micelles and thus increase the excretion of bile acids. To compensate for the bile acids loss, cholesterol is rapidly converted to bile acids in the liver which may lead to a reduction of the liver cholesterol content **(Myant and Mitropoulos, 1977)** and consequently may affect the total egg yolk's cholesterol content.

Immunity

GT had an advantageous impact on the immune response of chickens **(Farahat *et al*., 2016; Seidavi *et al*., 2017**; **Qui, 2022; Son *et al*., 2023**). The addition of GT to feed was unlikely to produce any negative impacts on the immune response **(Seidavi *et al*., 2017)**. **Abdel-Azeem (2005)** reported that the dietary addition of 0.25%, 0.50%, and 0.75% GT powders to growing Japanese quail promoted the production of high antibody titer. In the study of **Aziz-Aliabadi *et al*. (2023)**, the combination of GT leaf powder (2%) and mulberry leaf powder (2%) stimulated the humoral immunity by increasing the total anti-sheep red blood cells and immunoglobulin (Ig) G titers in broiler chickens. Similarly, dietary supplementation of chickens with green tea was associated with an enhancement of the cellular and humoral immune responses against coccidiosis with increasing the total IgG and IgM titers **(Abbas *et al*., 2017)**. **Song *et al*., (2016)** reported that the dietary supplementation of microencapsulated *Enterococcus faecalis* and *Camellia oleifiera* extract increased the titers of IgG and IgA, decreasing total cholesterol, and improved some biochemical parameters in serum. Polyphenols in GT (mainly catechins) have strong immunostimulant properties against important poultry viral infections such as avian influenza (AI) and Newcastle diseases **(Santini and Novellino, 2017)**. The mechanism by which the GT can modulate the antibody response may be attributed to the presence of catechins that possess antiviral properties (**Weber *et al*., 2003; Savi *et al*.,**

2006) or due to the reduction of the virus shedding in the droppings which in turn helps in minimizing the viral circulation among birds' species.

However, the antibody titers against AI virus (H5N1) and (H7N9) were lower in layers treated with GT at levels of 0.75% and 1.0% as well as 1.0%, respectively, than that in the control chickens **(Li *et al*., 2023)**. Similar results were obtained by **Lee *et al*., (2012)** who found that high doses of GT extract by-products significantly decreased the titer of AI virus (H9N2) in the caecal tonsils.

Microbial balance

The GT derivatives show antibiotic-like effects by non-selectively decreasing the total counts of all types of microflorae. The effects of GT polyphenols (2 g/kg diet) on the caecal flora in 24-day-old and 56-day-old chickens were studied **(Terada *et al*., 1993)** and the results showed a significant decrease in the number of total Bacteroidaceae but increase *Staphylococci* spp., Pseudomonads, and yeasts. However, on day 56, the *Lactobacilli* count was increased, while the enterobacteriaceae (*Proteus*) number was significantly decreased. Also, the study of **Cao *et al*. (2005)** showed that the semi-purified diets containing GT polyphenols reduced the counts of bacteroidaceae, bifidobacteria, Peptococcaceae, Eubacteria, and lecithinase-positive bacteria (*Clostridia*, *Staphylococci*, *Streptococci*, and *bacilli*). The reduction in coliform and *Clostridium (C.) perfringens* while increasing in the *Lactobacilli* counts was reported after feeding on GT powder **(Venables *et al*., 2008; Erener *et al*., 2011; Farahat *et al*., 2016; Mei *et al*., 2023)**. A mixture extract of lemon, GT, and turmeric showed inhibition of *Salmonella enteritidis* and *Campylobacter jejuni* growth on chicken breast fillets within 12 hours of incubation **(Murali *et al*., 2012)**.

The polyphenols such as olyphenolsis and catechins in GT **(Pasrija and Anandharamakrishnan, 2015; Wu *et al*., 2016)** can prevent the proliferation of pathogenic bacteria and ameliorate the animal intestinal health **(Hara, 2000)**. Polyphenols showed inhibitory effects on both Gram-positive and Gram-negative bacteria **(Gadang *et al*., 2008)**. The antibacterial activities of epigallocatechin-3-gallate on Gram-positive cocci (*Staphylococcus* spp.) and Gram-negative bacilli (*Escherichia coli*, *Klebsiella pneumoniae*, and *Salmonella* spp.) were studied **(Yoda *et al*., 2004)**. The authors detected that a concentration of 50–100 μg/mL could prevent the growth of *Staphylococcus* spp., and concentrations higher than 800 μg/mL could inhibit Gram-negative bacilli proliferation. Moreover, catechin derivatives showed antibacterial effects on *Clostridium* and *Bacillus* spores in terms of reduction of *C. botulinum*, *C. butyricum*, and *Bacillus cereus* spore counts **(Hara-Kudo *et al*., 2005)**. The antimicrobial activity of catechins in GT extract may be due to the galloyl moiety present in their structures **(Shimamura *et al*., 2007)**.

The positive impact of GT on some significant viral diseases such as AI was investigated **(Song *et al*., 2007; Deryabin *et al*., 2008)**. GT derivatives inhibited the 6 subtypes of human influenza virus and the 3 major types (A/H1N1, A/H3N2, and B type) as well as avian types (H2N2 and H9N2) through the prevention of viral adsorption on the red blood cells. The anti-influenza-viral activity of the synthesized GT catechin derivatives that have varying alkyl chain lengths and aromatic ring substitutions at the 3-hydroxyl group was investigated **(Song *et al*., 2007)**. A significant antiviral activity was found in derivatives carrying moderate chain lengths (7-9 carbons) when compared with derivatives with aromatic rings, whereas the 5′-hydroxyl group of the trihydroxy-benzyl moiety did not significantly show the antiviral activity. Moreover, the potential anti-viral lysing activity of a compound containing a mixture of GT extract, proline, lysine, cysteine, ascorbic acid, and selenium against AI virus (A/H5N1) was studied using different cultured cell lines, including PK, BHK-21, and Vero-E6 **(Deryabin *et al*., 2008)**. This compound showed a high antiviral activity for prolonged periods when compared to those of antiviral drugs such as oseltamivir and amantadine.

Feeding of poultry on GT showed positive influences on the reduction of some important parasitic diseases such as coccidiosis **(Jang *et al*., 2007)**. The incorporation of 0.5% and 2.0% GT in the feed of broilers for 2 weeks before *Eimeria maxima* infection resulted in a significant reduction of oocysts in fecal shedding by 38.5% and 51.5%, respectively **(Jang *et al*., 2007)**. The exact mechanism of GT against coccidiosis is not known. But cytokines such as interferon gamma may be increased following GT administration, as this cytokine can mediate a protective cell-mediated immune response against intracellular *Eimeria* spp. infection **(Yun *et al*., 2000)**.

CONCLUSIONS

According to the previously mentioned studies in poultry production systems, the dietary supplementation with GT derivatives for broilers and layers can enhance the productive performance parameters, implying its potential influences on broiler growth and carcass quality as well as the egg quality of layers. GT by-products can show potential antioxidant and anti-stress effects, improve some important blood parameters, promote immune response against important viral diseases, and have antibacterial, antiviral, and anticoccidial effects. More studies are still needed to elucidate the mechanisms of GT derivatives on poultry nutrition under different conditions.

Conflict of Interest

The author declares no competing of interest.

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